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# "Responsive" Access and Infrastructure

The key ideas in military technology today are speed, flexibility, interoperability, and economy. All of these apply to space as well. By holding new space technologies to these same strategic standards, we will secure the same fundamental advantages for the defense of our country.

Since the late 1950s, when Sputnik I first concentrated our attention, America has desired space supremacy. We finally attained it in the mid-1960s. That mastery of space comes with a danger, the danger of taking our edge for granted. For many years, other nations could only covet our space technologies. That is no longer the case. It's a new day, bringing new challenges, and America's success in space will once again require our full attention.

The knowledge of space technology has spread, and other nations have not been idle. These states know that for both military and commercial reasons a command of space is essential, and they are determined to gain that edge for themselves. Space capabilities are like oxygen. If you have it, you take it for granted. If you don't have it, it's the only thing you want.

To an extent that would amaze even the pioneers of our space program back when the first satellites went up from Cape Canaveral, America's command of space is central to our power and to our fortunes in the world. Our global positioning system (GPS) satellites make so many things work, from mobile phones to precision missiles, and provide the greatest free utility in the world. The constant precision navigation and timing information from our GPS satellites are used in every corner of the earth, and much of our global economy now depends on it.

These very same satellites transmit a constant and secure flow of data from reconnaissance assets such as the Predator. They give our Marines coordinates to track and find the enemy. With stunning and lethal effect, they help deliver missile strikes even in dense urban areas like the city of Fallujah. For these and many other reasons, our satellite system is absolutely essential to US military might. Were America's satellites ever to be attacked, the results could be devastating, and the economic effects would be the least of our worries.

The great danger is complacency. Our dominance in space is clear today, but by no means ensured for 10 or 15 years from now. Unless we are careful, taking nothing for granted, our fundamental advantages could easily become fatal liabilities.

The most basic problem is the large and often cumbersome scale on which we design and build our space systems. America's space program began as a heroic enterprise, requiring enormous resources and colossal structures. We still tend to think of it in those Apollo-like terms. This outlook served us well for decades, but needs some updating. Today in space technology, just as with other military systems, great size can be a vulnerability. The complexity of a single system can be a hindrance, and high cost in space technology is not necessarily a mark of quality.

The United States, over the years, has chosen to pack satellites with more and more capability, and to design them to last longer on orbit. The result has been ever-larger spacecraft, requiring ever-larger launch vehicles, that cost more money and take more time to deploy on orbit. We find ourselves paying more for systems that are more difficult to launch, and at times less reliable in operation. Add to that the fact that repairing or replacing a damaged satellite takes years.

Our mission at DARPA is to think ahead, and see to it that such things never happen. We believe the solution lies in a general strategy of responsive space access and infrastructure. Such a strategy would pursue five fundamental objectives:

- We must be quicker to launch our satellites. The long, labored, and too often delayed launch schedules of today must give way to a swifter, more flexible, and more affordable way of doing things.
- Our satellites must also be more flexible in what they can do, both on the ground and in orbit. We should focus less on global coverage—though that is crucial too—and more on our satellite capabilities over specific regions at critical moments.
- Payloads should be more self-sufficient, or else networked with land, sea, air, or other space sensors. This can be achieved by phasing out large-scale satellites in favor of a cluster of small satellites acting in concert.
- Satellites will need to be more maneuverable, to evade danger or search for threats, which means that mission operations must also be made more flexible and maneuverable. This will require autonomous operations, or sophisticated operations planning and command and control in operations centers.
- America's assets in space must network better with surface and airborne assets, to expand the conventional reach of our space operations.

These are the objectives, all far easier to describe than to meet. Let me tell you what DARPA is doing to rise to the challenge. At the center of our responsive space strategy are small launch vehicles. The small launch vehicle (SLV) is capable of

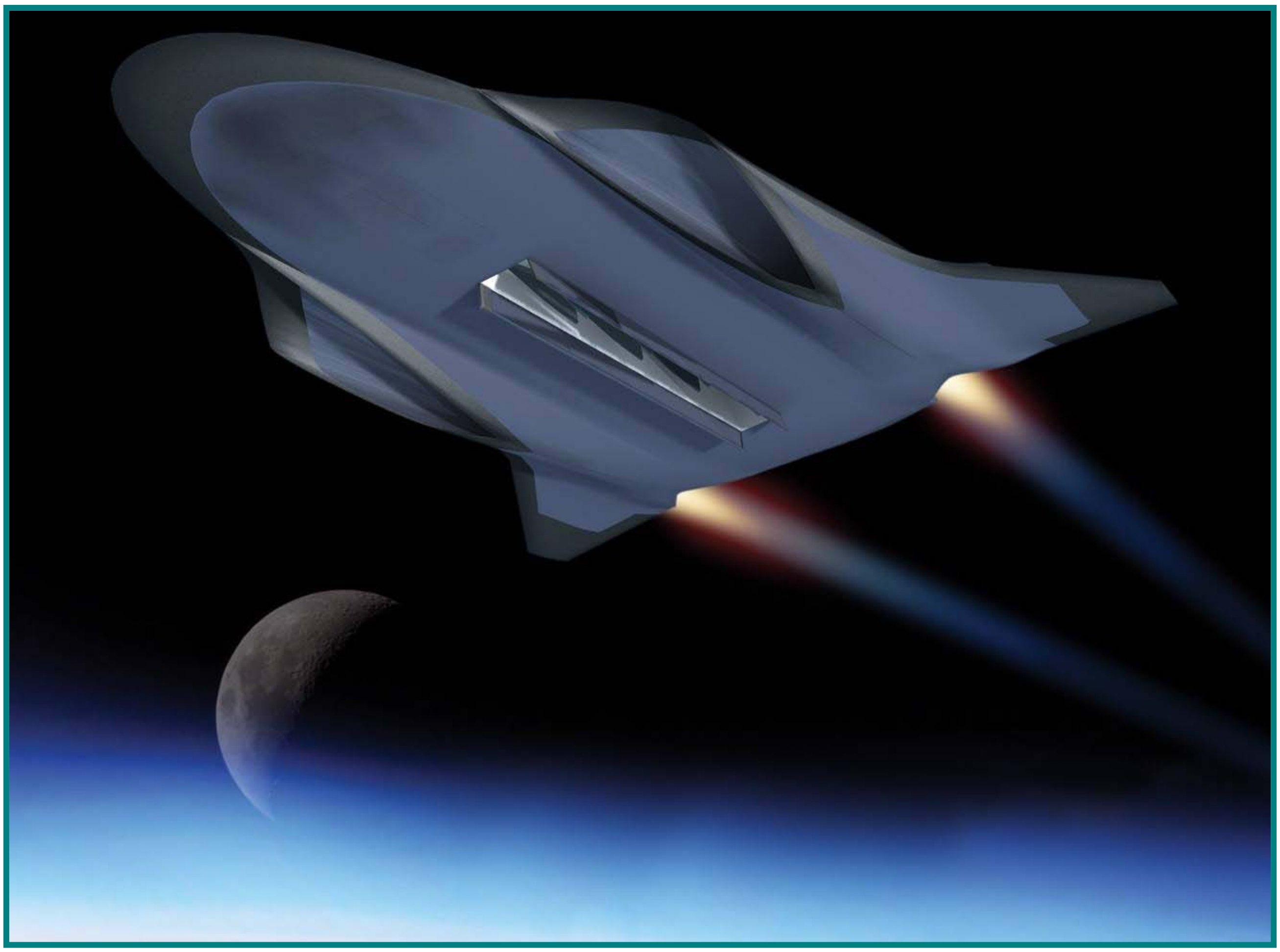
*Falcon Small Launch Vehicle (SLV )*

putting a 1,000-pound payload into low Earth orbit (LEO) on 24 hours' notice. This would be a radical departure from today's 6-month launch schedule. The cost reduction would be radical too: about $5 million as compared with today's $20–$30 million dollars.

Carried aloft by SLVs, even very large satellites may one day be put up in fragments to increase their flexibility and reliability. What's more, an SLV is designed to be launched by fewer than 10 people. It will use only safe liquid or hybrid fuel solutions, and keep space-range requirements at a minimum. Small launch vehicles are a crucial step in changing the way America does business in space, and we'll know soon how successful our efforts have been. The SpaceX Falcon 1 SLV is set to launch from the Reagan Test Site later next month.

For the far term, we are developing a reusable air-breathing hypersonic cruise vehicle for global reach applications. Hypersonic technologies, when they are fully developed, would help us to go the next mile and build a platform for reusable launch vehicles. Instead of disappearing somewhere in the ocean, such vehicles would function more like airplanes conducting sortie missions and returning home when the job is done. Both the SLV and reusable air-breathing hypersonic technologies are being developed in a program called Falcon.

On the satellite side, DARPA is looking at fractionated spacecraft that would fly together in formation. No longer will we depend on a large, expensive, and monolithic structure requiring a massive and costly booster. Instead, a satellite will be a collection of heterogeneous, microsat-like modules placed into orbit with multiple, small launch vehicles. There are various advantages to



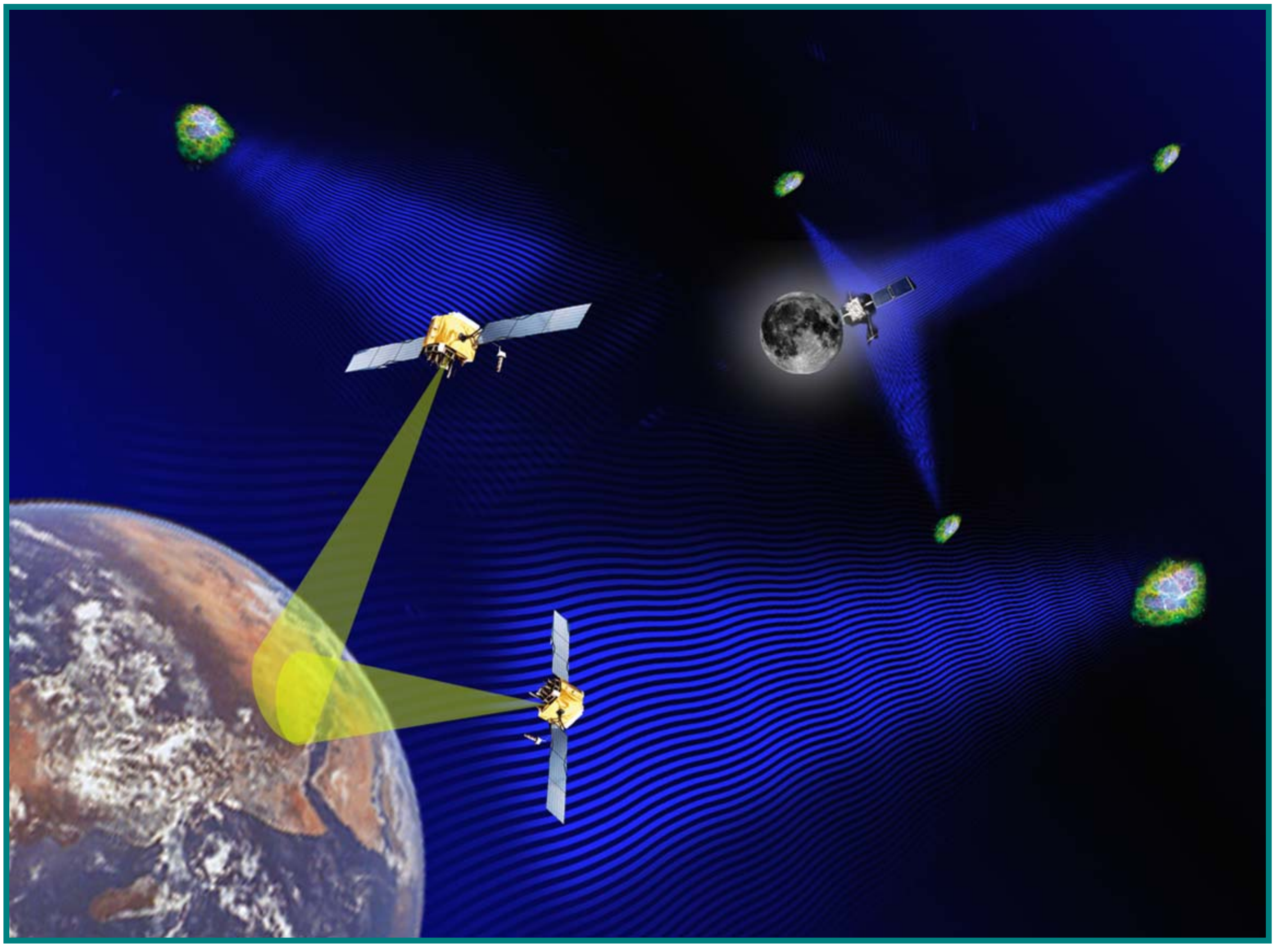
*Falcon Hypersonic Technology Vehicle*

this approach, not the least of which is a reduction in both cost and risk in the event of launch failure. It stands to reason that the more you have riding on a single launch, the more you will lose when things go wrong.

We wanted to put a number on it, so DARPA conducted a probabilistic study comparing losses in the case of a monolithic satellite and of a fragmented satellite. The difference is dramatic. When everything's added up, from support costs, to range use, to spacecraft replacement, it comes to a factor of 2. In other words, the total life-cycle cost for the sum of all the required modular launches can be nearly a factor of 2 less than the total life cycle costs for a single launch of a large spacecraft with the same capability. That's a complicated way of saying that, in satellite launch, it's not a good idea to put all your eggs in one basket.

The overarching proposition of this fractionated approach to satellites is this: The elements that unite spacecraft components into a single whole are data and power. Once those elements can be relayed through space and not through a harness, the structural backbone can be eliminated, with its undesirable side effects of transmitting forces and torques to the payload sensor. There are additional benefits as well, from flexibility to survivability, that all come naturally once that basic proposition is put into effect. We think that fast, flexible, fractionated, and formation-flying spacecraft is a new way of thinking about satellites, and we call it F6.

Having a flexible satellite architecture opens up many possibilities for servicing and resupply or even reconfiguration of a fractionated F6 satellite. We are working on routine, autonomous satellite



*X-ray Source Based Navigation for Autonomous Position Determination Navigation and Falcon Hypersonic Technology Vehicle* servicing technologies that will give our spacecraft new freedom of maneuver. This servicing capability will allow satellite coverage to be adjusted or optimized at will. It will enable our spacecraft to evade danger or direct threats. It will also greatly reduce the time-to-market of new technology into operational satellites, increasing mission performance more efficiently than through block replacements of satellite constellations. We are developing our satellite servicing and resupply technologies in a program called Orbital Express.

Farther still on the horizon is a satellite network requiring no supportive infrastructure at all from Earth. This system would compliment our existing LEO-based navigation assets, like GPS; however, in the event of a crisis, this system would be able to use X-rays from the stars to geo-locate. This bold, new venture, a revolutionary concept in space technology, is known as the X-ray Source Based Navigation for Autonomous Position Determination (XNAV) program and is entirely possible if we put our minds to it.

As in all we do, DARPA is counting on your best minds to see us through. We're thinking big in our responsive-space strategy, and I know we can expect the same of you. Before the first Falcon Hypersonic Cruise Vehicle can take flight, we need your best ideas on air-breathing hypersonic technologies, such as turbine-based combined cycle flow paths. We welcome your help with reusable high-temperature materials and thermal protection systems. Cryogenic, composite, and conformal fuel tanks offer another great challenge to us. Then there is the hard task of integrating all these technologies into affordable flight demonstrators.

To make the F6 a reality, we await your ideas to create efficient and lightweight inter-module power transmission. The system will also require ultrasecure data crosslinks, with antijamming and antispoofing capabilities. It will need relative navigation sensors and algorithms for passive, closed-loop cluster flying of multiple spacecraft. Another priority is to achieve functional synergies among the various technologies making the whole thing to work as one.

To make on-orbit servicing a reality, DARPA seeks your best ideas on standard satellite-servicing interfaces, autonomous guidance navigation and control systems, autonomous rendezvous, proximity operations, and docking technologies.

XNAV may present some of the hardest challenges. XNAV would take us beyond the star-tracker cameras and sensors now in use, and free a satellite completely from the need for navigational assistance on Earth. We need your help developing supersensitive X-ray detectors, navigational algorithms to infer time and position, timing models for pulsars, the supernova stars that emit electromagnetic energy, and new methods to fix the precise inertial position of those pulsars.

All this adds up to a tall order. Yet we at DARPA are confident in the mission and confident in you. The age of colossal boosters and spacecraft may be over, but the age of brilliant and heroic space endeavor goes on. With the same ingenuity, teamwork, and daring that got us this far, we will put a new generation of technology into space, and into the service of the United States of America.